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Impact of Openings on the Flexural Performance of Reinforced Concrete Beams

Dr. Mohammad Zuhair[1], Parikshit N. Deshmukh[2]

[1]*Professor, P. R. Pote Patil College of Engineering and Management Amravati, zuhairgcoe@gmail.com*
[2]*Research Scholar, P. R. Pote Patil College of Engineering and Management Amravati, parikshitndeshmukh@gmail.com*

Transverse openings are often provided to reinforced Concrete beams to accommodate utility ducts and pipes. This Technique is usually adopted to avoid the creation of dead space In structures caused by extended dropped ceilings and leads to Significant cost saving. On the other hand, the provision of openings through a beam creates a reduction in its strength and Affects serviceability. In this study, eight reinforced concrete beams were cast using M25 concrete. To ensure Compliance with the requirements provided by the codes of Practice and to check the required strength with the respective grade of concrete cube samples were casted for each pair of beams. The effect of size of openings from one support of beam at distance of L/4 was investigated through subjecting the beams to a two-point bending test after 28 days of curing. Maximum load capacity, first cracking load, and deflections were recorded and crack pattern and failure mode were evaluated. The provision of openings in the beams shows changes in terms of ultimate load capacity or first crack instant. Provisions of openings shows reduction in Ultimate strength. For 20 mm openings reduction is upto 12%, for 25 mm openings reduction is 22% and for 40 mm openings reduction is 25 %.

Keywords: Deflection, Ductility, Flexural strength, Hole shape, and location RC.

1. Introduction

In modern building construction, a network of pipes and ducts is essential for accommodating critical services such as water supply, sewage, air conditioning, electricity, telephone lines, and computer networks. Typically, these pipes and ducts are installed beneath the beam soffit and concealed with a suspended ceiling for aesthetic purposes, creating a dead space. Introducing transverse openings in floor beams allows these ducts to pass through, reducing dead space and resulting in a more compact and efficient design. While the space savings in smaller buildings may not be substantial, in multi-story buildings, reducing story height can lead to significant overall savings in building height, material usage for ducts, risers, walls, and foundation loads. The inclusion of openings in beams alters their structural behaviour. Openings can be circular, rectangular, or irregular in shape, and are often located near supports where shear stresses are high. Therefore, the impact of these openings on reinforced concrete (RC) beam performance must be carefully investigated. Factors such as the size, shape, placement, and spacing of openings play crucial roles in determining beam strength and stability. It is essential to analyse changes in ultimate load capacity, crack patterns, and flexural strength, and to compare these findings with solid beam sections.

A circular opening is considered large if its diameter exceeds 40% of the beam's effective depth (d), while a square opening is classified as large if its height surpasses 0.25d. Previous studies have tested RC beams with varying shapes, sizes, and horizontal locations of openings. Results indicate that openings located in the flexural zone have a lesser impact on beam performance compared to those in the shear zone. Among different shapes, circular openings cause the least reduction in ultimate load. Additionally, stress concentrations are observed around the corners of openings, often leading to transverse cracks. The presence of openings can also reduce beam stiffness, resulting in excessive deflection under service loads and altered internal force distributions. Research indicates that openings in beams introduce potential weak points, and failure patterns are often observed traversing the openings, except in cases where the opening is very close to the support. Numerous experimental and analytical studies have been conducted to evaluate the effects of openings on beams under different conditions. The current research focuses on varying hole diameters positioned at a distance of L/4 from one end of the beam.

1.1 Objectives

- To evaluate the impact of transverse openings on the structural behavior and flexural performance of reinforced concrete (RC) beams.
- To analyze the influence of opening size, shape, placement, and spacing on the strength, stiffness, and stability of RC beams.
- To study changes in ultimate load capacity, crack patterns, and flexural strength in beams with openings compared to solid beam sections.

2. EXPERIMENTAL PROGRAM

2.1 Description of Beams

M25-grade concrete beam specimens were prepared and tested, including two solid beams as reference samples for comparison with beams containing openings. Each beam measured 1000 mm in length with a span of 760 mm, a cross-section width of 100 mm, and a height of 150 mm. Table-1 outlines beam specifications, including opening diameters and distances from supports. Beam notation includes "S" for solid beams, "O" for beams with openings, and a number following "O" indicating the opening diameter in millimeters.

TABLE-1: Detail of beams that used in this research

Beams	Diameter of opening	Distance of opening from one end
S-1	--	--
O-20	20mm	250mm
O-25	25mm	250mm
O-40	40mm	250mm

Fig-1 Solid beams with Cubes of M25 Grade

Fig-2 Beams with opening of 20 mm dia.

Fig-3 Solid beams with Cubes of M25 Grade

Fig-4 Beams with opening of 20 mm dia.

2.2 Test Procedure

This research considered one variable: the size of the openings at fixed distance from one end of beam. The proposed three sizes are 20, 25 and 40 mm at a constant distance of 250 mm from the fixed end.

Fig-5 Testing Setup of Controlled beam

Fig-6 Testing Setup of O-20 beam

Fig-7 Testing Setup of O-25 beam

Fig-8 Testing Setup of O-40 beam

3. PERFORMANCE ANALYSIS

3.1 Flexural behaviour of beam test results

Table No-2: Two Point Load Test Result

Specimen	First cracking load (kN)	Ultimate cracking load (kN)	Distance from near support (mm)	Deflection (mm)
Solid beam (S-1)	65	81.4	190	4.2
Solid beam (S-2)	82	95.1	250	3.7
Beam with opening 20mm (O1-20)	78	81	194	5.8
Beam with opening 20mm (O2-20)	60	78.2	186	6.5
Beam with opening 25mm (O1-25)	70	78.5	190	7.8
Beam with opening 25mm (O2-25)	66	68.5	200	7.2
Beam with opening 40mm (O1-40)	60	67.4	210	8.3
Beam with opening 40mm (O2-40)	69	76.5	205	8.1

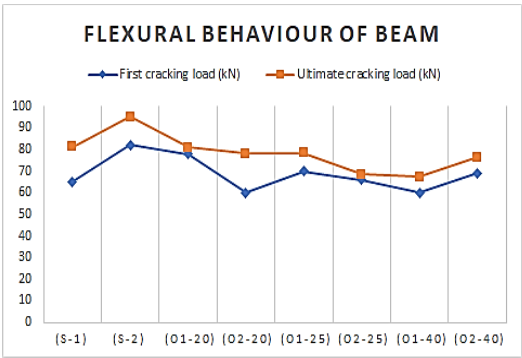

Fig-9 First cracking & Ultimate Load

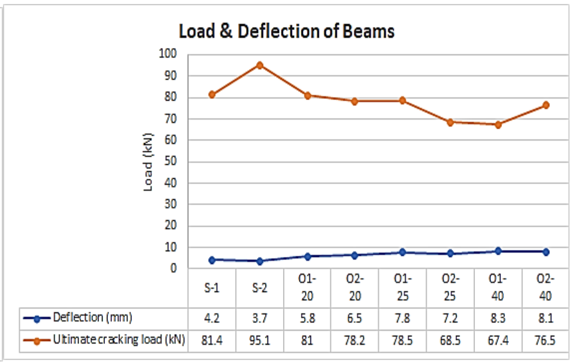

Fig-10 Load & Deflection of beam

3.2 Crack Pattern

Crack pattern and failure mode were observed, and Deflections at mid-span were recorded at each increment of Loading until failure.

Fig-5 Testing on Controlled beam

Fig-6 Testing on O-20 beam

Fig-7 Testing on O-25 beam

Fig-8 Testing on O-40 beam

4. CONCLUSIONS

The study was conducted to investigate the effect of hole opening on Flexural behaviour of RC beams.

The main findings of this study are:

- Openings in beams affect ultimate load capacity and crack initiation.
- The first flexural crack load is unaffected by openings, but shear cracks near openings occur earlier than in solid beams.
- Longitudinal bars above and below openings control cracks and flexural strains.
- Diagonal bars and stirrups near openings enhance beam strength.
- Openings reduce ultimate strength: 12% for 20 mm, 22% for 25 mm, and 25% for 40 mm openings.
- Additional reinforcement is needed to prevent strength reduction.

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